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A USER GUIDE TO THE DCIEM XDC-1 DIGITAL DECOMPRESSION CALCULATO--ETC(U)
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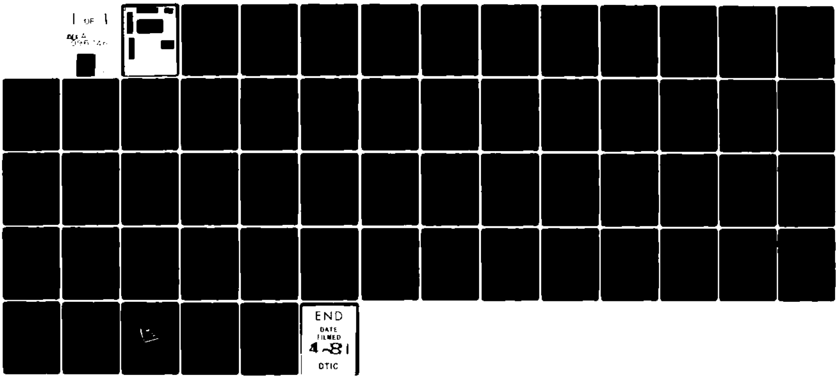

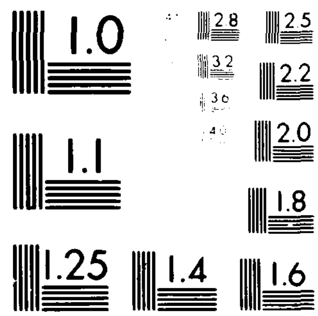

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Abstract

The XDC-1 Digital Decompression Calculator is a microprocessor-controlled computer based on the DCIEM pneumatic analogue decompression computer for calculating the safe ascent depth of divers. The calculator, which was developed by CTF Systems, Incorporated, on a contract with DCIEM, is a versatile instrument which can be used for planning and analysing dives in the calculator mode, or, for on-line dive monitoring in the real-time mode. The parameters used in the calculation of the decompression model are accessible from the key-board and can be changed for investigating theoretical modifications to the model. This report describes the XDC-1 and the various ways in which it can be used for calculating decompression profiles and monitoring dives. Examples of calculations are presented.

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I. INTRODUCTION

The XDC-1 Digital Decompression Calculator is a microprocessor-controlled computer based on the well-established DCIEM Kidd-Stubbs pneumatic analogue decompression computer for calculating the safe decompression of divers. The Kidd-Stubbs decompression model consists of four compartments in series. The equations describing this decompression model and the algorithm used for solving them are described in Appendix I.

The XDC-1 was developed by CTF Systems Inc., Port Coquitlam, B.C., for DCIEM. It is essentially a special purpose desk-top calculator capable of simulating the uptake and elimination of inert gases by the human body in response to increasing or decreasing ambient pressures. As such, it can be used as an alternative to published decompression tables and schedules for decompressing the diver. The XDC-1 calculates and displays the diver's safe ascent depth as a function of time, and decompression can be carried out by a continuous ascent procedure or by a staged ascent procedure to the surface. Unlike published tables, the XDC-1 is not restricted to a rigid depth-time profile and takes into account any variation in the depth which may occur.

The XDC-1 can be used in either a calculator mode or a real-time monitoring mode. In the calculator mode, the instrument can be used to simulate dives in artificial time by entering depth and time from the keyboard for applications such as dive planning and analysis. The operator can manipulate the parameters used in the decompression calculation to see the effect of certain changes or differing conditions at any time during the calculations.

In the real-time mode, the instrument can be used for on-line monitoring of an actual dive in a hyperbaric chamber or of a surface-supported dive, using as input the diver's actual depth. This can be done either manually from the keyboard or automatically by means of an external pressure transducer. Time is generated by the calculator's internal clock. The calculator mode and real-time mode can also be used interchangeably. For example, to monitor a dive already in progress, the previous dive history can be calculated in the calculator mode before the instrument is switched to the real-time mode. The output of the XDC-1 is obtained on a digital display, and if a hard copy is desired, analogue outputs are available for an X-Y plotter or strip chart recorder.

Simulated dives on two different gas mixtures can be calculated; e.g., with compressed air and with a 20% oxygen, 80% helium breathing mixture. The parameters used for these gases may be changed from the keyboard if other gas mixtures are required. The instrument, which is programmed for feet of sea water (fsw), can be used with any pressure units by reprogramming from the keyboard.

This application note describes the features of the XDC-1 and the various ways in which it can be used for calculating decompression profiles and for monitoring dives. Examples of calculations will be presented. A detailed description of the internal operation of the calculator will not be presented.

II. FEATURES OF THE XDC-1

Figure 1 shows the XDC-1 Digital Decompression Calculator and some of its main features. In this section, the switches, displays and keys will be described in detail, followed by an explanation of the operation codes, control codes, and the internal data registers.

A. Control Panel

1. Switches

Power: This is a key-operated switch on top of the instrument. During real-time monitoring, the key can be removed so that the instrument cannot be turned off.

CAL/REAL: This is a slide switch for selecting the calculator mode or the real-time mode. Once the real-time mode is set, the calculator mode cannot be re-established by resetting this switch back to CAL. A special control code must be entered from the keyboard to unlock the real-time mode.

HALT: This is a push button switch for halting all calculations in the calculator mode, or the look-ahead calculations in the real-time mode. All real-time operations are not affected. The switch must be held down for one calculation cycle before the operation is halted.

2. Numeric Display

Data Register Display: This is a five-digit number on the right hand side of the display. Any number entered from the keyboard and all calculated values go into this portion of the display.

Operation Code Display: This is a two-digit number on the left hand side of the display. This two-digit code identifies the operation being performed, or the location (internal data register) of the number appearing in the five-digit display. In addition, when control codes are being used, the first portion of the control codes must be transferred into this display. Operation codes, control codes and internal data registers will be described later.

3. Indicator Lights

GAS-1, GAS-2: These are two light-emitting diodes on the right hand side of the digital display for indicating which breathing gas mixture is being addressed. GAS-1 indicates a 20% oxygen, 80% helium breathing mixture and GAS-2 indicates compressed air. On turn-on, the calculations are set for compressed air and the GAS-2 light is on. GAS-1 and GAS-2 are selectable from

the keyboard by means of the control codes.

EXT: This light indicates if the depth is being entered as an external analogue voltage from a pressure transducer. On turn-on, this light is out, indicating that depth information is to be entered from the keyboard. The EXT mode is selected from the keyboard by a control code. Returning to the keyboard mode is also done by a control code.

REAL: This light is on when the CAL/REAL slide switch is in the REAL position, indicating that the real-time mode is set. This light, the display and all the other indicator lights which may be on will blink every six seconds indicating that real-time calculations are being done. Once the real-time mode is set, this indicator light will remain lit even though the CAL/REAL switch is moved to CAL. The light will go off only by unlocking the real-time mode with the appropriate control code or by turning the power off and then on again. The latter procedure, however, will destroy all previous calculations and any changes which may have been made in the memory.

HAZARD: This light indicates a hazard situation and comes on when the actual depth becomes less than the computed safe ascent depth during decompression.

4. Keyboards

Numeric Input Keyboard: The left hand keyboard consists of the digits 0 to 9 and the decimal point and is used for numeric input into the data register display (Figure 2a).

Control Keyboard: The right hand keyboard controls the operation of the calculator. The top row (blue keys) consists of the direct function keys, the second row (white keys) of the direct display keys, the third row (white keys) of a clear display key and two look-ahead calculation keys, and the fourth row (red keys) of indirect function keys for setting control codes or accessing the internal data registers (Figure 2b).

B. Description of Keys

1. Direct Function Keys

ED: **ENTER DEPTH.** This key is used for descending or ascending from the current depth to the depth shown in the data register display at a predetermined rate which is stored in internal register 16 for descent or internal register 15 for ascent. The depth is entered from the keyboard as depth from the sur-

face. After the key is depressed, the display shows actual depth for each calculation cycle as based on 0.1 minute (min) time increments.

__ET__: ENTER TIME. This key is used for advancing the time spent at the current depth by the amount shown in the display. The time, entered from the keyboard, must be in minutes from the current time and not the total dive time. For example, the time entered can be the bottom time, stage time, or surface interval for a repetitive dive. Calculations are based on 1.0 min time increments, except for the last increment which may be any portion of a minute. After the key is depressed, the display shows total time after each calculation cycle.

__A__: ASCEND. This key is used to ascend from the current depth to the depth shown in the data register display by the safe ascent criterion, i.e., continuous ascent where the actual depth is kept equal to the calculated safe ascent depth. If the actual depth is greater than the safe depth, ascent is made linearly to the safe depth in 0.1 min time increments at the rate specified in internal data register 15. When the actual depth reaches the safe depth, ascent is done continuously at 1 min time increments with the actual depth kept equal to the safe depth. If ascent to the surface is desired, 0 should be entered in the display. After the key is depressed, the display shows actual depth for each calculation cycle.

2. Direct Display Keys

__AD__: ACTUAL DEPTH. This key is used to display the actual depth in fsw from the surface. This key and the other two display keys are only operable when the XDC-1 is waiting in the calculator mode. When a calculation is being performed, these display keys are inoperative. In the real-time mode, these keys can be used at any time to select the variable to be displayed.

__TT__: TOTAL TIME. This key is used to display the total time in minutes from the start of the dive or from the initiation of the real-time mode.

__SD__: SAFE DEPTH. This key is used to display the calculated safe ascent depth in fsw from the surface. A negative value indicates altitude and that no decompression is necessary. The correspondence between safe depth and altitude is shown in Table 1. The initial value of the safe depth on turn-on is shown as −19.073 fsw.

__CL__: CLEAR. This key is used to clear the displays (both operation code and data register) in the event of an error during keyboard entry of data.

3. Look-ahead Calculation Keys

AT: ASCENT TIME. This key is used to estimate quickly the decompression time required to reach the surface from the current time and depth exposure. Calculations are based on a less accurate algorithm than in the normal calculate mode to speed up the calculations. Hence, the look-ahead calculation only gives an estimate and will not necessarily give exactly the same value as the A (Ascend) operation. The calculation does not affect the current depth and time.

ST: STAGE TIME. This key is used to estimate the time required at the current depth before ascent to the next stage depth is possible. Stage depths are normally set at 10 fsw intervals. However, this value may be changed by changing the contents of internal data register 14. This key can also be used to determine the time which must be spent on the surface following a dive before flying to a given altitude. As with the AT key, calculations are based on a less accurate algorithm and do not affect the current depth or current time.

4. Indirect Function Keys

TR: TRANSFER. This key is used to transfer the two right-most digits in the data register display into the operation code display.

OUT: OUTPUT. This key is used to look at the contents of the internal data register specified in the operation code display.

IN: INPUT. This key is used to replace the contents of the internal data register specified in the operation code display with the value shown in the data register display.

C. Operation Codes

The direct function keys, direct display keys, and the two look-ahead calculation keys all have a two-digit operation code associated with them, which will appear in the operation code display when the keys are depressed, to indicate which function is being performed. These operation codes are shown in Table 2.

D. Control Codes

The control codes are a set of instructions entered with the indirect function keys (TR, IN, OUT) to change the status of the calculator, such as initializing the decompression model, or setting the gas mixture to be used. These are listed in Table 3. The first part of the control code, XX, is entered from the numeric keyboard into the two right most positions in the data register display and then trans-

ferred to the operation code display. The second portion of the control code, Y, is then entered and either IN or OUT depressed:

XX TR Y IN (or OUT).

For example, "49 TR 1 IN" will set gas mixture 1. Some of these control codes will be described in more detail in other sections. Table 3 also shows which control codes are in effect on instrument turn-on (codes identified by asterisks). Any number, Y, which is not in the control code list will have no effect.

E. Internal Data Registers

Data are stored in internal data registers 01 to 36. These are listed in Table 4 with their initial turn-on values. These registers can be divided into two sections. The first 12 registers are working registers. All the results of the computation are stored in these registers and are updated after each calculation cycle. Registers 01 to 03 are the actual depth, total time and safe depth, and correspond to the operation codes of the respective direct display keys. Registers 04 to 07 are the pressures in the four compartments, scaled by the supersaturation ratio to give safe ascent values in gauge pressure units. The largest of these compartment safe depths is stored in register 03 as the safe depth. Register 08 is the actual depth in absolute pressure units. Registers 09 to 12 are the four compartment pressures in absolute pressure units. Registers 13 to 36 are constants used in the decompression calculations and are not changed by the calculations. Registers 13 to 16 are environmental and operational constants - the surface pressure in absolute pressure units, stage depth, and ascent and descent rates, respectively. The ascent and descent rates are stored as pressure per 0.1 min. Registers 17 to 28 are flow constants used in the decompression algorithm for the two gas mixtures and registers 29 to 36 are the supersaturation constants for each of the four compartments. All of these constants can be read or changed from the keyboard with the indirect function keys.

F. Analogue Outputs

Two analogue outputs are available at the rear of the XDC-1 for use with an X-Y plotter or strip chart recorder. These outputs are generated by an 8-bit digital-to-analogue converter. Full scale output is approximately 0.8 volts and it corresponds to 300 units. A plotter or recorder with adjustable input amplifiers will be required. After turn-on, or after an initialize operation, the X-output is internally set to the TOTAL TIME register and the Y-output is internally set to the ACTUAL DEPTH register. The outputs can be changed to other parameters from the keyboard.

G. Analogue Input

An anlogue input is available at the rear of the XDC-1 for entering an external signal representing depth information for real-time on-line dive monitoring. The input is only activated when the XDC-1 is in the REAL EXTernal Mode. The external signal,which must be a positive voltage between 0 to 10 volts, is converted by a 10 bit analogue-to-digital converter to give a depth indication between 0 and 511.5 fsw. A gauge pressure transducer calibrated to give 2 volts per 100 fsw should be used.

III. USING THE XDC-1 IN THE CALCULATOR MODE

A. Selecting the Gas Mixture

1. Compressed Air (GAS-2)

When the XDC-1 is turned on in the CALculator mode, the instrument is ready for use with compressed air (GAS-2) and descent and ascent rates at 60 fsw/min. The initial conditions are shown in Table 4. If other conditions such as different descent or ascent rates are required, then these can be entered as described later.

If the calculator has been set for the helium breathing mixture (GAS-1), the gas mixture can be set back to compressed air by using the following control code:

49 TR 2 IN.

2. Helium-Oxygen Breathing Mixture (GAS-1)

If a 20% oxygen, 80% helium mixture (GAS-1) is to be used, then this gas mixture can be set by the following control code:

49 TR 1 IN.

This control code must be used after an initialize procedure (next section) since the procedure resets the breathing mixture to GAS-2.

3. Special Gas Mixtures

Special gas mixtures (Appendix 2) can be used if the gas flow constants are known. These constants must be entered into internal data registers 17 to 22. These special mixtures should only be used for theoretical calculations since the decompression model has been experimentally validated only for compressed air and for a 20/80 oxygen-helium mixture.

B. Initializing the Calculator

If the XDC-1 has been used to calculate a dive profile and a new dive profile is to be calculated, or if a mistake has been made which necessitates a restart, the decompression model must be initialized back to surface conditions, i.e., all compartment pressures must be equilibrated at surface pressure, and time and depth reset to zero. There are two initialization levels which can be used depending on whether any of the data registers have been changed from turn-on conditions.

Level 1 initialize is set by the control code:

46 TR 1 IN (or OUT).

This initialization procedure resets all parameters back to their turn-on values (Table 4) and is equivalent to turning the XDC-1 off and then back on again. Any changes that have been made in the internal data registers 13 to 36 and any conditions set by the control codes will be lost.

Level 2 initialize is set by the control code:

46 TR 2 IN (or OUT).

This initialization procedure resets only the total time and the actual depth to zero and the compartment pressures to the surface pressure (determined by register 13). Any changes that have been made in any of the registers 13 to 36 will be retained. However, most conditions previously set by the control codes will be set back to turn-on conditions (Table 3), for example, gas mixture to GAS-2 if previously set to GAS-1, and analogue outputs to total time and actual depth. These conditions set by the control codes must be restored if required again.

An initialize to some other condition can be carried out by using the NULL operation:

CL ET.

This operation recalculates the compartment safe depths without changing the compartment pressures since the total time is not incremented. This is used, for example, in situations where the supersaturation constants or compartment pressures may have been changed manually from the keyboard, and it is desired to establish these new values in the calculation of the safe depths. The NULL operation is also used to output the contents of the total time and actual depth registers to the X and Y analogue outputs during the calibration of X-Y plotters.

C. Reading Contents of Internal Data Registers

In order to determine the contents of the internal data registers, the indirect function keys are used. The register number from Table 4 must be keyed into the data register display and transferred to the operation code display with the TR key. Then the OUT key is used to display the contents of that register in the data register display:

Register No. TR OUT.

For example, to determine the ascent rate being used, the procedure is

15 TR OUT.

D. <u>Changing the Contents of Data Registers</u>

To change the contents of any of the internal data registers, the register number must be keyed into the data register display and then transferred into the operation code display with the TR key. The new value required is then keyed into the data register display and IN depressed:

Register No. <u>TR</u> New Value <u>IN</u>.

After the <u>IN</u> key is depressed, the new value should appear with the most significant digit in the left-most position in the data register display with the decimal point in the appropriate location. Otherwise, the input operation has not been completed. As an example, if the descent rate, which is in register 16, is to be changed from the normal value of 60 fsw/min to 30 fsw/min, (i.e., from 6 fsw/0.1 min to 3 fsw/0.1 min), the procedure would be:

16 <u>TR</u> 3 <u>IN</u>.

After the input operation has been completed, the display should show "16 3.0000".

For registers 01, 02, and 03 (actual depth, total time, and safe depth), data can be entered directly by pressing the appropriate direct display key, entering the new value, and then pressing <u>IN</u>. For example,

<u>AD</u> 100 <u>IN</u>

will change the actual depth value in register 01 to "100.00".

E. <u>Using the Analogue Outputs with an X-Y Plotter</u>

The analogue X-output can be connected to the X-input and the Y-output can be connected to the Y-input of an X-Y plotter to obtain a graphical plot of a dive profile. At power turn-on or after an initialization operation, the X-output is automatically set for TOTAL TIME and the Y-output for ACTUAL DEPTH. The maximum value available from the two outputs is 300 units, i.e., 300 min for the time axis and 300 fsw for the depth axis.

To set the reference zero on the plotter, the calculator should be initialized to set the total time and the actual depth to zero, and the NULL operation used to transfer these zero values to the analogue outputs:

46 <u>TR</u> 1 <u>IN</u>
<u>CL</u> <u>ET</u>.

The initialization or power turn-on operations, by themselves, do not set the analogue outputs to zero.

The maximum X and Y units will be determined by the size of the graph paper being used. For example, if graph paper 25 cm by 38 cm is being calibrated for 1 unit/min, the X-output would be set for 300 min and the Y-output for 250 fsw maximum depth. To set these maximum limits for both the X and Y outputs, the following procedure is used:

TT 300 IN
AD 250 IN
CL ET.

The pen can then be set at X = 30 cm and Y = 25 cm using the controls on the plotter. If the depth is to be plotted with zero at the top of the graph and maximum depth at the bottom, then the Y-input connector at the plotter can be reversed to change the polarity.

To recheck the zero, an initialization and NULL operation can be carried out, or alternatively,

TT 0 IN
AD 0 IN
CL ET

can be executed. The pen will also restart from zero in either the X or Y direction if TT or AD become greater than 300 units.

If graph paper 18 cm by 25 cm is used, then the above procedure can be used with TT = 250 and AD = 180 for the maximum limits. Although the X and Y outputs can be changed to display parameters other than total time and actual depth; for convenience, the calibration should be done using total time and actual depth.

To change the X and Y outputs to display other parameters, the following control codes are used:

50 TR Register No. IN (for X-output)
51 TR Register No. IN (for Y-output).

For example, to set the Y-output to the safe depth,

51 TR 03 IN

is used. However, negative safe depth values will appear as positive values since the digital-to-analogue converter outputs only the absolute value of the digital number.

The following data registers can be obtained on the analogue outputs:

01	Actual depth in gauge pressure units
02	Total time in minutes
03	Safe depth in gauge pressure units
04-07	Safe depth for compartments 1 to 4, respectively, in gauge pressure units
08	Actual depth in absolute pressure units
09-12	Pressures in compartments 1 to 4, respectively, in absolute pressure units.

It should be noted that, when a Level 1 or Level 2 initialize is performed, the X and Y outputs will revert back to total time and actual depth and must be re-established if other parameters are still required.

Figure 2 shows an example of a dive profile on an X-Y plotter.

F. Using the XDC-1 with a Strip Chart Recorder

With a strip chart recorder which generates the time axis, only depth needs to be on the analogue outputs. Calibration is essentially the same as for the X-Y plotter. For a one-pen strip chart recorder, the Y-output is connected to the recorder to display actual depth. The pen can be set for the zero by

AD 0 IN
CL ET

and for the maximum depth required by

AD Max. Value IN.

The zero should be rechecked after the maximum depth has been set. If the safe depth is required instead of actual depth, the output can be changed, after calibration, by

51 TR 03 IN.

With a two-pen or two-channel strip chart recorder, both analogue outputs can be used. The Y-output can be connected to one pen or channel for recording actual depth. The X-output can be used with the other pen or channel for safe depth. For calibration, the TT key should be used to set the zero and the maximum safe depth value required. Then the X-output can be set for safe depth by

50 TR 03 IN.

A strip chart recorder is better suited for monitoring dives in the real-time mode than in the calculator mode.

IV. APPLICATIONS OF THE CALCULATOR MODE

A. Basic Dive Profile

The basic dive calculation is for a fixed time at some bottom depth, and then continuous ascent (by the safe ascent criterion) back to the surface. Descent is carried out linearly at the rate specified in internal data register 16 and calculations are carried out at 0.1 min intervals. The bottom phase is entered as the time interval between reaching bottom and the beginning of the ascent phase. Calculations are carried out at 1 min increments. Ascent back to the surface is initially linear at the rate stored in register 15 until the computed safe depth is attained. Calculations are done at 0.1 min increments during this linear ascent. Once the safe ascent depth is reached, the time base increases to one minute increments and the actual depth is kept equal to the safe depth until the surface is reached.

The descent rate and initial ascent rates are set at 60 fsw/min. If different rates are desired, then the appropriate values (in fsw/0.1 min) can be entered in register 16 for descent and register 15 for ascent.

Procedure

1. 46 TR 1 IN	Initialize, not necessary if XDC-1 just turned on; 46 TR 2 IN, if changes made in registers.
2. (Section IIIA)	Select gas mixture if required.
3. Depth ED	Bottom depth in fsw below surface.
4. TT	To check time to reach bottom. If depth entered in step 3 is an exact multiple of the descent rate, the time displayed will be 0.1 min longer than that calculated directly.
5. Bottom Time ET	Time spent on bottom before start of ascent.
6. 0 A	Ascent back to surface (0 fsw).
7. TT	To check total time of dive.

Example 1 shows a standard dive to 150 fsw for 15 min (including descent time) on a 20/80 oxygen-helium breathing mixture.

Clearing Errors

If an error is made in keying in the depth or the bottom time,

the CL key can be used to clear the error as long as the function keys, ED or ET, have not been activated. If the ED or ET key has been pressed with incorrect information, then it will be possible to stop the calculations using the HALT switch. If the required target depth or time has not been reached, then the correct depth, or the difference between the target time and the current time can be entered. For example, if 150 fsw had been entered by mistake instead of 125 fsw and the calculations were halted at 90 fsw, then "125 ED" can be keyed in to complete the correct calculations. If the error were not detected before the target value was exceeded, then the calculator must be initialized and the procedure restarted.

Use of Look-Ahead Keys

The look-ahead calculation key, AT, can be used at any time the calculator is in the idle mode to obtain a quick estimate of the decompression time back to the surface. For example, after step 5, AT can be used instead of "0 A" if only an approximate time is required. The status of the decompression model is not changed by the AT key. Thus, it is possible to add more bottom time if desired, or complete the calculations to surface with the A key. A less accurate algorithm with a variable step time is used for the look-ahead calculation so there may be a slight discrepancy between the results of the AT and A calculations. The AT key uses 1 min increments for the first 10 min of decompression time, 3 min increments for the next 30 min and 10 min increments for the remaining time. Example 2 shows how to calculate the optimum bottom time for a dive if the total time of the dive, including decompression, is to be approximately one hour.

Use of HALT Key

In order to determine the actual time-depth values during ascent to the surface, an X-Y recorder can be connected to the analogue outputs. Without an X-Y recorder, it is possible to obtain some of this information by using the HALT switch periodically during the A operation to stop the calculations and allow the corresponding total time to be read with the TT key. The ascent operation should be restarted with "0 A" and the calculations allowed to proceed for a few cycles before the HALT switch is used again. The procedure can be repeated until the surface is reached. Example 3 shows a dive to 150 fsw using the HALT key.

B. Repetitive Dive Profile

A repetitive dive consists of two or more dives separated by some surface interval. Each dive to depth is calculated the same as the basic dive profile except that the initialization procedure is used only before the first dive.

Procedure

1.	46 TR 1 IN	Or 46 TR 2 IN - Initialize.
2.	(Section IIIA)	Set gas mixture if required.
3.	Depth ED	1st dive.
4.	TT	Check time to reach bottom.
5.	Bottom Time ET	
6.	0 A	
7.	Surface Interval ET	In minutes.
8.	Depth ED	2nd dive.
9.	TT	(Optional).
10.	Bottom Time ET	
11.	0 A	

If a third dive is required, the new surface interval is entered as in step 7 and the procedure continued. If a new dive profile is desired, then the calculator must be initialized. Example 4 shows the procedure applied to three dives to 140 fsw (also shown in Figure 2).

C. Random Dive Profile

A random dive profile with variable rates of descent or ascent or variable bottom depth can be generated by breaking down the profile into short time segments. The ascent or descent rates can be calculated for each segment and the appropriate values stored in registers 15 and 16 (in fsw/0.1 min). Then "Depth ED" should be used. For upward excursions, "Depth ED" should also be used instead of "Depth A". The decompression phase can be calculated as usual by "0 A" after the appropriate initial ascent rate has been stored in register 15. Example 5 shows a random dive to 150 fsw.

D. Staged Ascent Decompression Profile

Dive profiles using stage decompression can be calculated using the stage time (ST) look-ahead calculation key. The stage depth increment is stored in register 14 and is normally set to 10 fsw. However, this value can be changed if desired. The descent to bottom and the bottom-time phase are calculated as for the basic dive profile. At the beginning of the ascent phase, the first stop depth must be calculated. This is generally done by looking at the safe depth (with

the SD key) and selecting the first stop as the first stage depth greater than the safe depth. For example, if the stage depth increment is set to 10 fsw and the safe depth is equal to 26.9 fsw, the first stop would be set to 30 fsw.

After the first stop is reached by using ED, the safe depth should be checked again. In some cases, it may be possible to ascend to the next stage depth because the safe depth has decreased sufficiently during the ascent to the estimated first stop.

In other cases, for deep depths where ascent to the first stop may take several minutes or when the safe depth is close to the initial estimate, it may be necessary to take the first stop as the second stage depth greater than the safe depth. For example, on a dive to 300 fsw, if the safe depth reads 15 fsw at the start of ascent, the initial estimate should be chosen as 30 fsw instead of 20 fsw because by the time ascent to 30 fsw is completed, the safe depth will have increased to 29 fsw. In case of doubt, the second stage depth greater than the safe depth should be taken since it is always possible to ascend to the next shallower stage depth, if necessary.

At each stage depth, the stage time required is calculated by using the ST key. As with the AT key, a less accurate algorithm and the variable calculation time increment (1, 3, and 10 minutes) is used to calculate the time. Since the ST operation is a look-ahead calculation, the status of the decompression model is not changed and it is necessary to enter this stage time with an ET operation to advance the decompression model. Then an ED operation can be carried out to the next stage depth.

Procedure

1. 46 TR 1 IN	Or 46 TR 2 IN - Initialize.
2. (Section IIIA)	Set gas mixture if required.
3. Depth ED	
4. TT	
5. Bottom Time ET	
6. SD	
7. First Stop ED	
8. SD	Check Safe Depth to see whether the depth can be advanced to the next Stage Depth. If so, advance to next depth with ED key.

9. <u>ST</u> — Calculate Stage Time.

10. <u>ET</u> — Advance the decompression model by Stage Time.

11. Next Stop <u>ED</u>

12. <u>ST</u>

13. <u>ET</u>

14. Next Stop <u>ED</u> — Continue until surface is reached.

The technique shown here can be used for generating decompression tables for comparison with other published tables. Example 6 shows a dive to 180 fsw for 15 min.

E. <u>Oxygen Decompression</u>

The driving force for inert gas elimination is provided by the difference between the compartment pressures, which are stored in registers 09 - 12, and the pressure in register 08. Normally, the value in register 08 is automatically set to the absolute value of the actual depth register. (All calculations are based on total gas pressure rather than inert gas partial pressure.) For oxygen decompression, the value in register 08 should be zero since there should be no inert gas in the breathing mixture. The driving force would then be equal to the compartment pressures.

In practice, in hyperbaric chambers, oxygen decompression is only about 80% efficient, i.e., there is about a 20% leakage of ambient gas around the face mask. Hence, 20% of the ambient pressure value should be entered into register 08 for calculating the driving force. As an example, if the actual depth were 60 fsw (93 fsw absolute), and 20% leakage is assumed around the face mask, the value entered into register 08 should be 18.6 (93 x 0.2) fsw absolute.

Data can not normally be entered directly into register 08 but must be done through the actual depth register. However, this would require negative values which cannot be entered from the keyboard. A control code is available,

52 <u>TR</u> 1 <u>IN</u>,

which allows data to be entered directly into register 08 by the usual method of

8 <u>TR</u> Leakage component <u>IN</u>,

and which prevents this value from being altered by the contents of

the actual depth register. Since the required value is in absolute pressure units, there is no problem with negative numbers. The value entered into register 08 will remain until changed manually to another value.

For stage decompression, the control code should be used at the first stage depth where oxygen is used. Then the appropriate value can be entered into register 08, and the stage time calculated with the ST key and then entered into the decompression model with the ET key. Ascent to the next stage is done as usual with the ED key. The value in register 08 is then changed to the appropriate value for that stage. The procedure is repeated until the surface is reached.

For continuous decompression, the standard procedure is used until the depth where oxygen is to be used. This can be carried out by "Oxygen depth A", if the depth is shallower than the safe depth, or by "Oxygen depth ED", if the depth is deeper than the safe depth. The control code can then be used. Subsequent calculations will only be approximate since the value in register 08 will not change automatically to reflect the change in the actual depth during the decompression. The HALT key can be used to stop the calculation to allow register 08 to be changed periodically.

When the oxygen breathing period has been completed or when the surface has been reached, the control code

52 TR 2 IN

is used to clear the oxygen mode, so that register 08 can be set to the actual depth again. This control code must be used for clearing the oxygen mode. The Level 1 and Level 2 initialization control codes will not reset the model to standard decompression.

Example 7 shows a stage decompression with oxygen after 30 fsw. Note, however, that these oxygen decompression calculations have never been validated experimentally.

F. Excursion Diving From Saturation

For calculating excursion dives from saturation at some depth, the four compartments in the decompression model and the actual depth must all be set to the saturation depth.

Procedure

1. AD Saturation depth (gauge) IN

2. TT Time value IN

3. 09 TR Saturation depth (absolute) IN

4. 10 TR Saturation depth (absolute) IN

5. 11 TR Saturation depth (absolute) IN

6. 12 TR Saturation depth (absolute) IN

7. CL ET

An alternative method for setting the decompression model to the saturation depth is the following:

Procedure

1. 13 TR Saturation depth (absolute) IN

2. 46 TR 2 IN Level 2 initialize

3. 13 TR 33 IN

4. AD Saturation depth (gauge) IN

5. CL ET

The Level 2 initialize in step 2 sets the compartment pressures (registers 09 to 12) to the values in register 13. The surface value, 33 fsw, must be replaced in register 13 as a reference value for calculating the safe depth. The NULL OPERATION in step 5 initializes the model to the saturation depth.

From the saturation depth, upward excursions to the safe depth can be conducted using the ED key. For downward excursions, the normal dive procedure can be used, except ascent should be made back to the saturation depth. If continuous ascent is required, then

Saturation depth A

should be used. Stage decompression back to the saturation depth can be done as described previously. The AT look-ahead calculation will give the ascent time back to the surface and not the ascent time to the saturation depth.

It should be noted that saturation diving has not been experimentally validated for this decompression model. Although decompression back to surface can be carried out by the normal method, i.e., by "0 A", the decompression time calculated is much shorter than those using published techniques. Hence, there is some doubt as to the validity of using the present supersaturation ratios for saturation dives since these have been developed for subsaturation dives. The supersaturation ratio should probably be more conservative for the fourth compartment and the initial rate of ascent much slower than 60 fsw/min for saturation dives.

G. Flying After Diving

The length of time which must be spent on the surface after diving before flying to a given altitude can be calculated with the ST key. Internal data register 14, which normally contains the stage depth increment, can be replaced with the altitude equivalents which are shown in Table 1. Each altitude equivalent should be entered as a positive value. For example, for flight to 8,000 feet, the altitude equivalent is entered by

14 TR 8.482 IN.

Normal dive procedure as described previously should be used for calculating the dive profile. Once the surface is reached, ST is pressed. The display will show the time in minutes required before ascent to the specified altitude is possible. *It should be noted that* these calculations are only approximate and have never been validated experimentally. In practice, one should wait 24 hours on the surface before flight or travel to altitude.

H. Diving at Altitude

Decompression calculations can be performed for diving at elevations above sea level. One method for determining which table or profile to use is the similarity principle where an equivalent depth for a sea level dive is calculated by dividing the actual dive depth by the altitude at the dive site in atmospheres (atm). The XDC-1, on the other hand, can automatically compensate for the reduced pressure at altitude and can calculate the exact profile to be followed. In addition, the XDC-1 can take into account whether or not the diver is acclimatized at that altitude.

The parameters which must be changed in the XDC-1 are the surface pressure in register 13 and the four supersaturation offset constants in registers 33 to 36. These parameters must be multiplied by the altitude in atmospheres (from Table 1).

The following procedures will be given for a dive at 6000 ft altitude (P_a = 0.8 atm).

Procedure: Non-acclimatized diver at 0.8 atm

1. 46 TR 1 IN — Initialize
2. 13 TR 26.4 IN — Surface pressure (0.8 x 33)
3. 33 TR 7.92 IN — Supersaturation constant (0.8 x 9.9)
4. 34 TR 7.92 IN — Supersaturation constant (0.8 x 9.9)

5. 35 TR 7.92 IN Supersaturation constant (0.8 x 9.9)

6. 36 TR 7.92 IN Supersaturation constant (0.8 x 9.9)

7. CL ET

The NULL operation in step 7 initializes the model but maintains all the compartment pressures (registers 09 to 12) at sea level values (33 fsw). This situation would apply to a diver who has flown to the dive site and then dived immediately or shortly after arriving.

Procedure: Acclimatized diver at 0.8 atm

1. 13 TR 26.4 IN Surface pressure (0.8 x 33)

2. 33 TR 7.92 IN Supersaturation constant (0.8 x 9.9)

3. 34 TR 7.92 IN Supersaturation constant (0.8 x 9.9)

4. 35 TR 7.92 IN Supersaturation constant (0.8 x 9.9)

5. 36 TR 7.92 IN Supersaturation constant (0.8 x 9.9)

6. 46 TR 2 IN Level 2 initialize.

The Level 2 initialize sets all the compartment pressures (registers 09 to 12) to the values at altitude. This situation would apply to a diver who has spent a day or more at altitude before diving.

Example - dive to 100 ft for 30 min at 6000 ft altitude.

A dive to 100 ft for 30 min at 60 ft/min descent and ascent rates at sea level gives 20.4 min of decompression. The similarity principle gives the equivalent sea level depth at 6000 ft altitude as 125 fsw with the descent and ascent rates adjusted to 75 ft/min, giving a decompression time of 29.3 min. The procedure outlined for the acclimatized diver at 6000 ft gives 29.4 min of decompression which is close to the value derived from the similarity principle. However, the actual decompression profiles generated by the similarity principle (depths multiplied by 0.8) and the procedure outlined here for the acclimatized diver, will be slightly different because of the non-linear nature of the Kidd-Stubbs mathematical model.

For the non-acclimatized diver, the procedure outlined above gives 41.3 min for decompression, which is about 41% greater than for the acclimatized diver.

Note that no compensation has been made for the difference between the densities of sea water and fresh water for these calculations. The density of fresh water could be worked in to obtain

slightly different decompression times. It should also be noted that the correction for altitude has never been validated experimentally for the XDC-1.

I. Conversion to Metric Operations

All calculations can be done in metric units of pressure instead of fsw by changing the constants used in the decompression calculations manually through the keyboard. The XDC-1 will continue to operate in metric units until the calculator is switched off or a Level 1 initialize is used. Hence, it is important to use only Level 2 initialize between dives.

Operation of the XDC-1 for air dives in meters of sea water is done by changing the following data registers:

1. 13 TR 10.06 IN
2. 14 TR 3 IN
3. 15 TR 1.8 IN   Gives 59 fsw/min
4. 16 TR 1.8 IN
5. 17 TR 83.67 IN
6. 18 TR 259.58 IN
7. 19 TR 259.58 IN
8. 20 TR 259.58 IN
9. 21 TR 259.58 IN
10. 22 TR 259.58 IN
11. 33 TR 3.02 IN
12. 34 TR 3.02 IN
13. 35 TR 3.02 IN
14. 36 TR 3.02 IN
15. 46 TR 2 IN

The Level 2 initialize in step 15 is necessary to establish the metric units for the compartment pressures and safe depths. The safe depth, SD, should show -5.8165.

For helium calculations, the following steps should be inserted

after step 14:

15\. 23 TR 157.49 IN

16\. 24 TR 238.88 IN

17\. 25 TR 238.88 IN

18\. 26 TR 238.88 IN

19\. 27 TR 238.88 IN

20\. 28 TR 238.88 IN

21\. 46 TR 2 IN

Access to helium calculations can be made as usual through the control code 49 TR 1 IN. If only helium calculations are required and not air, then the helium values can be inserted in registers 17 to 22 to avoid having to use the control code 49 TR 1 IN after each initialization procedure.

For operation in kilopascals (kPa), the values to be entered into the following data registers are:

Register 13	101.11
14 to 16	as required
17	841.07
18 to 23	25.822
33 to 36	30.334

The safe depth value at surface will be indicated as -58.44.

For operation in bars, the values to be entered into the data registers are:

Register 13	1.0111
14 to 16	as required
17	8.4107
18 to 23	2582.2
33 to 36	0.30334

The safe depth at surface will be indicated as -0.58441.

J. Conversion to PSI Operation

For compressed air work in tunnels and caissons, decompression schedules are usually carried out in pounds per square inch gauge (psig). The procedure for changing the operation to psig is similar to that for metric operation (the values given are for air):

1	13	TR	14.7	IN
2.	17	TR	122.3	IN
3.	18	TR	177.62	IN
4.	19	TR	177.62	IN
5.	20	TR	177.62	IN
6.	21	TR	177.62	IN
7.	22	TR	177.62	IN
8.	15	TR	0.5	IN
9.	16	TR	1	IN
10.	33	TR	4.41	IN
11.	34	TR	4.41	IN
12.	35	TR	4.41	IN
13.	36	TR	4.41	IN
14.	46	TR	2	IN

The safe depth should show -8.4963 after the Level 2 initialize. The descent rate (register 16) for compressed air work is usually 10 psi/min. The ascent rate (register 15) is usually no greater than 5 psi/min. Normal practice for compressed air work decompression is by several stages with decreasing rates of linear ascent. If staged ascent is required, then the appropriate value can be stored in register 14.

If helium calculations are required, then 230.2 should be entered in register 23, and 163.5 should be entered in registers 24 to 28.

K. Preloading Compartment Pressures

Calculation of new dive profiles usually require that the calculator be initialized back to surface conditions before entering the relevant information for each profile. In some instances, initialization back to surface conditions is not necessary and computation time can be shortened by starting the calculations at some time into the dive if the compartment pressures are known at the time. For example, suppose four or five different dive profiles, which are initially identical, are to be calculated. During the first profile calculation,

the calculations are stopped at the end of the common section. The data in registers 01, 02, 09, 10, 11, and 12 are recorded using

Register No. <u>TR</u> <u>OUT</u>.

The first profile calculations are then completed in the normal manner. For the subsequent profiles, instead of initializing, the calculations are started at the end of the common section by entering the previously recorded values back into the appropriate registers by

Register No. <u>TR</u> Previous Value <u>IN</u>.

After all the values have been entered, a NULL operation must be used to initialize the model at that time,

<u>CL</u> <u>ET</u>.

This method can save considerable computation time and tedious keying in of complicated dive profiles if repetitious calculations are required.

L. Changing the Time Base for Increased Calculation Speed

The XDC-1 takes approximately 1.4 seconds per calculation cycle. For descent or ascent (<u>ED</u> operation), the time increment for calculation is 0.1 min, so that, for example, if the ascent rate between 30 fsw and surface were 1 fsw/min as in treatment schedules, calculations would be done for every 0.1 fsw and it would take about 7 min to complete the calculations. Such small depth or time increments are not necessary for slowly changing pressures and it is possible to change the time scale so that calculations can be performed in one-tenth of the usual time.

To compensate for the fact that the calculation cycle in the XDC-1 is set for 0.1 min time increments, it is necessary to multiply the gas constants in registers 18 to 23 by the time expansion factors. Hence, for 1 fsw/min, the rate in register 15 would be 1 fsw/0.1 min and the 6 gas constants would be 791.20 (10 x 79.120) to obtain calculations for 1 min time increments. The total time taken for the calculations as obtained from key <u>TT</u> will have to be multiplied by the time scale factor as well to get the correct time.

Similarily, the time scale can be expanded for calculations during periods of constant depth (ET operation) which takes place at 1 min time increments. Calculations can be speeded up by a factor of 2 or 5, or possibly, by a factor of 10 for very long periods although the accuracy may be degraded. For short time periods, the tradeoff will be the time saved in calculations versus the time required to change the contents of the relevant data registers.

Such an enhancement of the calculation speed would be essential for analysing or predicting the status of the attendant in a treatment schedule while the treatment is going on. One cannot afford to spend 15 or 20 min performing calculations since the decompression status of the attendant will be changing constantly. When using the speed enhancement procedure, one should record the contents of registers 09 to 12 and the actual depth and total time in the event that the procedure has to be aborted and restarted. As a general rule, recording of registers 09 to 12 periodically is useful during the calculations of long dive profiles.

The procedure shown below is for ascent at 1 fsw/min at 10 times normal calculation time (for air).

Procedure (10X speed enhancement)

1. 18 TR 791.2 IN (10X value in register)
2. 19 TR 791.2 IN
3. 20 TR 791.2 IN
4. 21 TR 791.2 IN
5. 22 TR 791.2 IN
6. 23 TR 791.2 IN
7. 15 TR 1 IN (10X rate in fsw/0.1 min)
8. TT OUT — Record TT
9. TT 0 IN
10. Depth ED — Ascend to required depth
11. TT OUT — Determine time taken.

The time taken in step 11 must be multiplied by the speed enhancement factor (which in the procedure shown above is X10) to get the actual time taken. This value should be added to the original time recorded in step 8 to get the total time for the dive and it should be entered into TT if required. The contents of registers 18 to 23 should be returned to the original values if calculations for the next part of the dive are to be done at normal speed. If a different speed enhancement rate is required, for example 5 times normal speed, then new values must be entered into registers 18 to 23.

V. USING THE XDC-1 IN THE REAL-TIME MODE

A. Real-Time/External Input Mode

1. Calibration of the Pressure Transducer

The input signal required by the XDC-1 must be a positive voltage between 0 and 10 volts. This voltage is converted by a 10 bit analogue-to-digital converter to give a depth indication between 0 and 511.5 fsw. The pressure transducer should be calibrated to give approximately 2 volts per 100 fsw and should be a gauge unit (i.e., giving 0 volts at atmospheric pressure). The XDC-1 has a transducer input jack on the rear which supplies an excitation voltage of ± 15 volts to the transducer. The mating connector required is a Cannon XLR-4-11C. A screwdriver adjustment for calibration is accessible from the front of the XDC-1 (lower right hand corner).

A suggested pressure transducer for the XDC-1 is the Viatran Model 218-15 Option M18 (0-150 psig). This unit is driven by ± 15 volts with an output of 0 to 10 volts and can be interfaced directly to the XDC-1 without any external electronics. Zero and span adjustments are available on the transducer body.

To calibrate the transducer, the following procedure should be used:

CAL/REAL IN REAL

48 TR 1 IN (Set external mode)

AD (Set display to actual depth).

The minimum digital reading from the analogue-to-digital converter is ".00000" and, as a result, the display will not change for any voltages less than zero. In order to set the zero on the transducer, the zero adjustment screw on the transducer should be adjusted to display ".50000" on the XDC-1. This offset can be removed later.

To set the gain of the transducer, the pressure should be set to 133.6 psig and the screwdriver adjustment on the XDC-1 adjusted to display approximately "300.00". The span adjustment on the transducer can then be used to set the depth to "300.50". The 0.5 offset can then be removed by reducing the pressure to 2.2 psig. The display should read "5.5000". The zero adjustment on the transducer can then be adjusted to set the display to "5.0000".

The linearity should then be checked for depths between 0 and 300 fsw as follows:

Pressure (psig)	Depth (fsw)
0.0	0
22.3	50
44.5	100
66.8	150
89.1	200
114.4	250
133.6	300

The span adjustment should be adjusted slightly, if necessary, so that all depths are within ± 1 fsw. Since the sampling time of the analogue input is 0.1 min in the real-time mode, the display may not change immediately after the pressure is changed. The display will blink when the pressure input has been read into the calculator and the display will change to the new value.

2. Monitoring a Dive

Real-time monitoring of a dive can be accomplished by supplying an external signal from a pressure transducer which is monitoring the diver's depth or the hyperbaric chamber pressure. The CAL/REAL switch must be in the REAL position and the EXTernal input mode selected by the appropriate control code. The display and any of the indicator lights which may be on will blink every 0.1 min to indicate that the external input signal is being read and that the decompression model is being updated. Any of the display keys, AD, TT or SD can be selected at any time to show the appropriate value.

The following procedure should be used for monitoring a surface-supported dive or a dive in an hyperbaric chamber. The pressure transducer should be connected to the diver's pressure line or to the hyperbaric chamber. The XDC-1 should be turned on and the transducer allowed to warm up to operating temperature. If a strip chart recorder or X-Y plotter is to be used, then calibration and the assignment of the output registers should be made at this time. If 20/80 oxygen-helium gas mixture is to be used, then GAS-1 should be set by the control code 49 TR 1 IN.

Before the dive commences, the real-time mode can be set by

CAL/REAL to REAL

48 TR 1 IN (Set external mode)

AD (Display actual depth).

The external mode should be set only after the CAL/REAL switch is set to the REAL position.

For the descent and bottom phases of the dive, the actual depth can be displayed. The operation code portion of the display will show 01 (actual depth). During the descent, the depth will not change continuously since the pressure sampling time is 0.1 min. For example, if the descent rate is 60 fsw/min, the display will change by 6 fsw every 0.1 min. During the latter part of the bottom phase and during the ascent, the safe depth can be displayed by pressing SD. The operation code will change to 03.

If the total time is desired, then TT can be pressed. The operation code will show 02 and the time will be updated every 0.1 min. Note that, unless the total time has been zeroed at the start of the dive (see below), the total time displayed will be the time since the CAL/REAL switch was set to the REAL position and not the elapsed time of the dive.

The function keys ED, ET, and A are disabled so that incorrect information cannot be entered inadvertently. The ED key will appear to function if any value is entered. For example, "300 ED" will cause the display to show "41 300.00" and the display and the indicator lights will blink every 0.1 minutes. However, by pressing "AD", it can be seen that the actual depth is still controlled by the external input. Pressing "AD Depth IN" will also seem to change the actual depth, register 01. However, by pressing AD again, the display will return to the external input value after several calculation cycles and there will have been no effect on the decompression model.

Pressing "ET" will only change the operation code to 42 and pressing "A" will change the code to 43. For example, "50 ET" will cause the display and the indicator lights to stop blinking. This does not indicate that real-time calculations have stopped. If any of the display keys (AD, TT or SD) are pressed, the display and lights will start blinking again. Real-time calculations will proceed regardless of whether or not the display or lights are blinking, as long as the REAL indicator light is on.

The AT and ST look-ahead keys are still functional and can be used at any time. The indirect function keys, TR and OUT, can be used to look at the contents of any of the registers. However, care must be taken that IN is not pressed inadvertently since the contents of the registers can be changed, quite often with no knowledge of the original values in the register. This is particularly important in the case of the compartment pressures since the whole dive history can be altered and the decompression status be made invalid.

For real-time monitoring of a dive, the POWER ON key can be removed so that the instrument cannot be accidently shut off, hence erasing the memory. In case of a power failure, the computer can be restarted by following the procedure described under Mixed Mode Calculations (Section V (C)).

3. Zeroing the Total Time

Since the total time starts counting as soon as the REAL position is set, it is possible to obtain the elapsed time of the dive by setting the external mode first and then switching to REAL at the beginning of the descent. However, this procedure is not recommended as there is a possibility of a transient coming through the external input when the CAL/REAL switch is moved and momentarily setting the actual depth to some high value and, as a result, changing the equilibrium values in the compartments.

It is possible to zero the clock at any time during the real-time mode by the following procedure. It is assumed that the real-time mode has already been set, followed by the external input mode as described earlier.

1. TT 0 IN Display should show "02 .00000".
2. TT Time starts to increment.

The first step puts zero in register 02 but does not enter it into the calculations. Although the display will blink every 0.1 min, the time displayed will remain at zero and will not increment. As soon as TT is pressed in the second step, the zero is entered into the *decompression calculations* and the time will start incrementing. Therefore, before the dive commences, the first step can be done and the calculator left until the start of the dive. As soon as the descent starts, step two can be carried out to start the elapsed time measurement.

4. Look-ahead Calculations

If the time required to reach the surface on the optimum ascent profile is desired, the look-ahead key, AT, can be pressed. The calculation is done in the dead time between real-time calculations. When the real-time calculation is taking place, the look-ahead calculation is suspended. The look-ahead calculation can be stopped by pressing the HALT switch.

If staged decompression is being conducted, then the time remaining at that stage (before ascent to the next stage is possible) can be determined by pressing ST.

B. Real-Time/Keyboard Input Mode

Real-time monitoring of a dive can be done if a pressure transducer is not available by entering all depths at the appropriate times from the keyboard. The operation is similar to that described in the previous section except that the external mode is not set. The ED key is functional and data can be entered into the actual depth register. The keys, ET and A, are non-functional, and the total time can be

zeroed as described previously.

With the ED key, the depth goes immediately to the specified depth. The rates of ascent and descent stored in registers 15 and 16 have no effect. All other consideration for the real-time external mode apply.

C. Mixed Mode Calculations

The calculator and real-time modes can be used together for applications such as monitoring a dive already in progress, or for getting the computer back on-line after a power failure. The past dive history is keyed into the XDC-1 in the calculator mode until the current time. Then the calculator is switched to the real-time mode and the external input selected. Time will start incrementing from the value in the total time register prior to the real-time mode being set. Monitoring can then proceed in the real-time mode as described previously.

Another example of the use of the two modes is for monitoring a repetitive dive where the decompression computer may not have been used for the first dive, or if used, the computer may have been turned off (thus destroying the memory of the dive) since the second dive had not been planned or foreseen at that time. The first dive and the subsequent surface interval can be calculated in the calculator mode and the real-time mode started at the commencement of the second dive. If an accurate record of the first dive is not available, the profile should be approximated with the error being on the safe side. It may be worthwhile to record the actual depth, total time, and the four compartment pressures just prior to setting the real-time mode.If a restart is required, these values can be reloaded into the appropriate registers as described in the section on preloading the registers (Section IV (K)) and the past dive history calculations need not be repeated.

Monitoring a complex dive profile in the real-time mode and then switching to the calculator mode to investigate several possible dive scenarios can also be done. In this case, the XDC-1 must be taken out of the real-time mode by

CAL/REAL to CAL

47 TR 32 IN (Unlock real-time mode)

48 TR 2 IN (Set keyboard input mode).

Simply switching the CAL/REAL switch to CAL will not unlock the real-time mode. The control code is required to prevent unauthorized tampering with the XDC-1 during real-time monitoring of a dive.

Once the XDC-1 has been put in the calculator mode, the actual depth, total time, and the four compartment pressures must be recorded. Then possible dive situations can be tried, for example, comparing staged decompression with and without oxygen. The first situation can be calculated starting at the conditions reached at the end of the real-time mode. For the second situation, instead of initializing the decompression model, the previously recorded values obtained at the end of real-time monitoring are reloaded back into the appropriate registers. To return back to the real-time mode, the previously recorded values are again loaded into the appropriate registers, the decompression model updated to the current time in the calculator mode, and the real-time and external input modes re-established.

D. Oxygen Decompression

Although the oxygen decompression feature of the XDC-1 has never been validated experimentally, it can be used for comparative purposes during a dive. The procedure is similar to that described for the calculator mode (Section IV (E)). During the descent, bottom phase and initial ascent, the procedure described for real-time dive monitoring is used. When oxygen breathing during decompression is started, the control code

52 TR 1 IN

is used to set the oxygen mode. The inert gas leakage component around the face mask, for example, 20% of the ambient pressure, must be entered into register 08. This can be done while in the real-time external input mode. The safe depth can then be monitored. However, since the actual depth no longer affects register 08, the contents of register 08 must be changed periodically from the keyboard to take into account any changes in the actual depth.

When oxygen breathing is suspended temporarily, for example, during an air break, register 08 must be set back to the actual depth in absolute units. When oxygen breathing is terminated, the control code

52 TR 2 IN

must be used to take the XDC-1 out of the oxygen mode.

E. Diving at Altitude

The XDC-1 can be used for real-time monitoring of dives at elevations above sea level. Before the real-time mode is set, the initialization described under applications of the calculator mode (Section IV (I)) for acclimatized or non-acclimatized divers should be performed. Then the real-time mode can be set.

It should be noted that the XDC-1 is calibrated and set for feet of seawater whereas diving at altitude involves diving in fresh water. If a pressure transducer is used for external input of depth, the displayed depth will be about 2.5% less than the actual depth in fresh water. The transducer could be calibrated so that the displayed depth is the same as the actual depth in fresh water. This would also provide an additional small safety factor.

APPENDIX 1

THE KIDD-STUBBS DECOMPRESSION MODEL

The decompression model incorporated in the XDC-1 consists of four compartments in series. The equations describing this model were originally developed for a pneumatic analogue computer in which the gas flow into and out of the compartments was controlled by "slip-flow". Each compartment was specified by a volume, V, and a pneumatic resistor characterized by two flow constants, a and B. The general formulation of this four compartment model describing the uptake and elimination of gases is (for four non-identical compartments)

$$\frac{dP_1}{dt} = \frac{a_1}{V_1}(B_1 + P_a + P_1)(P_a - P_1) - \frac{a_2}{V_1}(B_2 + P_1 + P_2)(P_1 - P_2)$$

$$\frac{dP_2}{dt} = \frac{a_2}{V_2}(B_2 + P_1 + P_2)(P_1 - P_2) - \frac{a_3}{V_2}(B_3 + P_2 + P_3)(P_2 - P_3)$$

$$\frac{dP_3}{dt} = \frac{a_3}{V_3}(B_3 + P_2 + P_3)(P_2 - P_3) - \frac{a_4}{V_3}(B_4 + P_3 + P_4)(P_3 - P_4)$$

$$\frac{dP_4}{dt} = \frac{a_4}{V_4}(B_4 + P_3 + P_4)(P_3 - P_4)$$

where: P_1, P_2, P_3, P_4, are the four compartment pressures and P_a is the ambient pressure.

In the Kidd-Stubbs formulation of the decompression model, the four compartments are identical so that instead of 12 constants (a_i, B_i and V_i, $i=1,4$), there only two

$$A = a_i/V_i = 79.12 \times 10^{-6} \quad \text{(for air)}$$
$$B = 274.5. \quad \text{(for air)}$$

In the XDC-1, the 12 constants have been reduced to 6 constants:

$$B = \text{constant for all compartments}$$
$$A_i = a_i/V_i \quad i = 1, 4$$
$$A_0 = a_{i+1}/V_i \quad i = 1, 3.$$

These 6 constants give sufficient flexibility for changing the gas transfer characteristics of the four compartments if required.

This set of four first-order, nonlinear differential equations can only be solved by numerical techniques. The method used is the improved Euler method (Heun formula)

$$Y_{n+1} = Y_n + (Y_n' + f(x_n + h, Y_n + hY_n'))h/2$$

where $Y_n' = f(x_n, Y_n)$.

Once the four compartment pressures have been found, they are then scaled and offset by the supersaturation constants to obtain the safe ascent depth, D, for each compartment:

$$D = X_i P_i - Y_i - P_{atm}, \quad i = 1, 4,$$

where P_{atm} is the atmospheric pressure.

In the Kidd-Stubbs model, all the X's are set to 0.72202 and all the Y's are set to 9.9 fsw. The safe ascent depth for the complete model, D_{sa}, is the largest of the four compartment safe depths. The effect of the offset is to make the supersaturation ratio depth-dependent, with the ratio being more conservative at the deeper depths.

For the look-ahead calculations, the one-step Euler method is used to approximate the ascent and stage times:

$$Y_{n+1} = Y_n + hY_n'.$$

APPENDIX 2

MODIFYING THE DECOMPRESSION MODEL

The decompression model incorporated in the XDC-1 can be modified by changing the model parameters from the keyboard. Although the model is restricted to four compartments in series, it is possible to generate profiles similar to those generated by a parallel configuration of compartments. The modifications described in this section are theoretical and should be used purely for purposes of comparison with standard decompression profiles.

CALCULATIONS WITH OTHER GAS MIXTURES

In addition to the preprogrammed gases, compressed air and 20/80 oxygen-helium, other gas mixtures can be used by replacing the parameters in registers 17 to 22. These gas constants are functions of the molecular weight and the viscosity of the gas mixtures and can be found from the following relationships:

$$A = A_{air}\, \eta_{air}/\eta_{gas}, \text{ and}$$

$$B = B_{air}\left[\frac{\eta_{gas}}{\eta_{air}}\right]\left[\frac{M_{air}}{M_{gas}}\right]^{1/2},$$

where M is the molecular weight and η is the viscosity. The gas constant A is stored in registers 18 to 22 and the gas constant B is stored in register 17. For example, for a 20/80 oxygen-argon mixture, the gas constants are

$$A = 66.48 \text{ and}$$
$$B = 283.3,$$

and for a 10/90 oxygen-helium gas mixture, they are

$$A = 73.07 \text{ and}$$
$$B = 611.7.$$

The A and B constants will change the effective half-time of the compartments since the half-time of each individual compartment is given by

$$T_{1/2} = \frac{1}{A(B+2P_f)} \ln\left[2 - \frac{P_i - P_f}{B+P_i + P_f}\right]$$

where P_i and P_f are the initial and final pressures, respectively, (specifying where the half-time was measured). With a large value of B, such as for oxygen-helium, the half-time will be smaller than for a larger molecular weight gas; hence, the compartments will pressurize and eliminate gas much faster.

Diving with gas mixtures other than compressed air and 20/80 oxygen-helium has not been experimentally validated for the decompression model incorporated in the XDC-1. Limited diving has been done with 20/80 oxygen-argon to 200 fsw but an additional safety factor of 4 fsw has been added to the safe ascent depth during decompression.

CHANGING THE DECOMPRESSION MODEL

The model parameters can be changed arbitrarily to obtain different half-times for the compartments and thus change the rates of uptake and elimination. In the standard Kidd-Stubbs decompression model, all four compartments are identical. The uptake and elimination of gas are non-linear with pressure and asymmetric, elimination occuring at a slower rate than uptake.

In the general formulation of the decompression model (Appendix 1), there are 12 separate constants which can be varied independently. The particular version incorporated in the XDC-1 has been modified so that there are only 6 constants, A_0, A_1, A_2, A_3, A_4, and B. This still allows sufficient flexibility for changing the model. For example, these constants can be changed to reduce the non-linearity with pressure and hence reduce the asymmetry between uptake and elimination. This can be accomplished by making the constant B sufficiently larger than the maximum pressure encountered during the dive. Hence, as the half-time of the compartment is then given by

$$T_{1/2} = (\ln 2)/AB,$$

the constant A must also be changed to give the appropriate half-time.

Another example of a modification which could be made is to change the distribution of half-times for each compartment. With the Kidd-Stubbs model where the half-times are identical, the maximum effective half-time for the series configuration is limited. The third and fourth compartments become the controlling compartment much sooner than would be normally expected and this leads to extremely long decompression times at depths below 10 fsw in certain subsaturation cases. By changing the distribution of the half-times, in particular, by changing A_1 and A_4, the unnecessarily long decompression times can be eliminated for subsaturation dives. The fourth compartment would then become the controlling one for bottom times approaching saturation.

CHANGING THE SUPERSATURATION RATIOS

The Kidd-Stubbs decompression model uses a single depth dependent supersaturation ratio which is applied to each compartment. There are two constants which specify the ratio: the first, 0.72202, in registers 29 to 32 and the second, 9.9, in registers 33 to 36.

These two constants can be changed to make the safe ascent depth deeper or shallower than the conventional Kidd-Stubbs model. For example, for oxygen-argon dives, DCIEM practise has been to make the actual depth four fsw deeper than the predicted safe depth during the decompression. By changing the constants in registers 33 to 36 to the value 5.9, the predicted safe depth would show the actual depth (including the safety factor) to be followed during decompression.

The supersaturation ratio need not be the same for all compartments and can be changed for each individual compartment. For example, to eliminate the long subsaturation decompression times associated with the third and fourth compartments for the standard Kidd-Stubbs model, the two ratio constants for the third and fourth compartments can be made equal to zero so that only the first two compartments are monitored. However, this modification will not be valid for bottom times approaching saturation. For saturation dives, the fourth compartment ratio should be made more conservative than the conventional Kidd-Stubbs value.

TABLE I

ALTITUDE EQUIVALENTS OF NEGATIVE SAFE DEPTH VALUES

Altitude		Safe Depth Indication
(feet)	(atmospheres)	(fsw)
0	1.000	0
2000	0.930	-2.31
4000	0.864	-4.49
6000	0.801	-6.56
8000	0.743	-8.49
10000	0.688	-10.31
12000	0.636	-12.02
14000	0.587	-13.61
16000	0.542	-15.12
18000	0.500	-16.51

TABLE 2

OPERATION CODES

Code	Key	Function	Mode	Real-Time
41	ED	Enter Depth	Input	Yes*
42	ET	Enter Time	Input	No
43	A	Ascend	Input	No
44	AT	Ascent Time	Output	Yes
45	ST	Stage Time	Output	Yes
01	AD	Actual Depth	Output	Yes
02	TT	Total Time	Output	Yes
03	SD	Safe Depth	Output	Yes
00	CL	Clear Display		Yes

*Keyboard Input Only

TABLE 3

CONTROL CODES

OP Code	Data Reg.	Action	Real-Time
46	00001	Level 1 Initialize. Resets all parameters to initial turn-on values and clears display.	No
46	00002	Level 2 Initialize. Resets only compartment pressures, time and depth and clears display.	No
47	00032	Unlocks the XDC-1 from the real-time mode to calculator mode. REAL/CAL switch must be in CAL position.	Yes
48	00001	Set EXT Mode. Changes the depth input from keyboard to external analogue signal in.	Yes
*48	00002	Changes depth input from EXT Mode to keyboard mode.	Yes
49	00001	Set Gas Mixture 1 (20% O_2, 80% He)	Yes
*49	00002	Set Gas Mixture 2 (compressed air).	Yes
*50	00002	Set X-output to TOTAL TIME.	Yes
*51	00001	Set Y-output to ACTUAL DEPTH.	Yes
51	00003	Set Y-output to SAFE DEPTH.	Yes
50 51	000NN 000NN	Set analogue output to contents of internal data register NN.	Yes
52	00001	For oxygen decompression calculations.	Yes
*52	00002	Return to normal operation after oxygen decompression.	Yes

* Initial turn-on conditions

TABLE 4

INTERNAL DATA REGISTERS

Working Registers

Reg. No.	Data	Units	Initialization Value
01	Actual Depth	fsw gauge	0.0
02	Total Time	minutes	0.0
03*	Safe Depth	fsw gauge	-19.073
04*	Safe Depth-Compartment 1	fsw gauge	-19.073
05*	Safe Depth-Compartment 2	fsw gauge	-19.073
06*	Safe Depth-Compartment 3	fsw gauge	-19.073
07*	Safe Depth-Compartment 4	fsw gauge	-19.073
08**	Actual Pressure	fsw absolute	33
09	Pressure-Compartment 1	fsw absolute	33
10	Pressure-Compartment 2	fsw absolute	33
11	Pressure-Compartment 3	fsw absolute	33
12	Pressure-Compartment 4	fsw absolute	33
Constants Registers			
13	Ambient Pressure on Surface	fsw absolute	33
14	Stage Depth	fsw	10
15	Ascent Rate	fsw/0.1 minute	6
16	Descent Rate	fsw/0.1 minute	6
17	Flow Constant B for Gas 2	fsw	274.5
18	Flow Constant A_0 for Gas 2	$10^6 fsw^{-1} minutes^{-1}$	79.12
19	Flow Constant A_1 for Gas 2	$10^6 fsw^{-1} minutes^{-1}$	79.12
20	Flow Constant A_2 for Gas 2	$10^6 fsw^{-1} minutes^{-1}$	79.12
21	Flow Constant A_3 for Gas 2	$10^6 fsw^{-1} minutes^{-1}$	79.12
22	Flow Constant A_4 for Gas 2	$10^6 fsw^{-1} mintues^{-1}$	79.12
23	Flow Constant B for Gas 1	fsw	516.7
24	Flow Constant A_0 for Gas 1	$10^6 fsw^{-1} minutes^{-1}$	72.81
25	Flow Constant A_1 for Gas 1	$10^6 fsw^{-1} minutes^{-1}$	72.81
26	Flow Constant A_2 for Gas 1	$10^6 fsw^{-1} minutes^{-1}$	72.81
27	Flow Constant A_3 for Gas 1	$10^6 fsw^{-1} minutes^{-1}$	72.81
28	Flow Constant A_4 for Gas 1	$10^6 fsw^{-1} minutes^{-1}$	72.81
29	Supersaturation Constant X_1		0.72202
30	Supersaturation Constant X_2		0.72202
31	Supersaturation Constant X_3		0.72202
32	Supersaturation Constant X_4		0.72202
33	Supersaturation Constant Y_1	fsw	9.9
34	Supersaturation Constant Y_2	fsw	9.9
35	Supersaturation Constant Y_3	fsw	9.9
36	Supersaturation Constant Y_4	fsw	9.9

* Data cannot be input into these registers since the contents are derived from contents of registers 09 - 12.

** Data cannot be input into register 08 since the value is derived from register 01, except when the control code 52 TR 1 IN is used to set oxygen decompression.

EXAMPLES OF CALCULATIONS

1. Standard Dive - Calculate the total time for a dive to 150 fsw for 15 min on a 20/80 oxygen-helium breathing mixture.

Keystrokes	Display at End of Operation	AD	TT	SD	Comments
46 TR 1 IN	00 00000	.00000	.0000	-19.07	Initialize
49 TR 1 IN	49 00001				GAS-1 light on
150 ED	41 150.00	150.0	2.6	-11.99	
12.4 ET	42 15.000	150.0	15.0	27.87	
0 A	43 .00000	0.0	35.1	- 1.53	Total time 35.1 min

2. Standard Dive - Determine the bottom time for a dive to 100 fsw if the total time, including the decompression, is to be approximately one hour (on air).

Keystrokes	Display at End of Operation	AD	TT	SD	Comments
46 TR 1 IN	00 00000	.00000	.0000	-19.07	Initialize GAS-2 light on
100 ED	41 100.00	100.0	1.7	-16.99	
30 ET	42 31.700	100.0	31.7	18.98	Try 30 min
AT	44 19.000	100.0	31.7	18.98	Gives about 51 min
3.3 ET	42 35.000	100.0	35.0	20.62	Try 3 more min
AT	44 22.000	100.0	35.0	20.62	Gives about 57 min
1 ET	42 36.000	100.0	36.0	21.07	Try 1 more min
AT	44 22.000	100.0	36.0	21.07	Gives about 58 min
0 A	43 .00000	0.0	59.4	- 0.93	Bottom time of 36 min (including descent time gives one hour total time.

EXAMPLES OF CALCULATIONS

3. Standard Dive - Calculate detailed profile for dive to 150 fsw for 15 min on air by using the HALT switch.

Keystrokes	Display at End of Operation	AD	TT	SD	Comments
46 TR 1 IN	00 00000	.00000	.0000	-19.07	Initialize GAS-2 light on
150 ED	41 150.00	150.0	2.6	-13.95	
12.4 ET	42 15.000	150.0	15.0	20.81	
120 ED	41 120.00	120.0	15.5	21.44	Record AD, TT and SD for all the following steps
90 ED	41 90.000	90.0	16.0	21.56	
60 ED	41 60.000	60.0	16.5	21.26	
30 ED	41 30.000	30.0	17.0	20.59	
0 A HALT	43 20.422	20.4	18.1	18.70	Use HALT when display shows 20.4
0 A HALT	43 17.081	17.1	20.1	15.55	Use HALT after every 2 calculations from this step
0 A HALT	43 14.108	14.1	22.1	12.74	
0 A HALT	43 11.446	11.4	24.1	10.21	
0 A HALT	43 9.0524	9.0	26.1	7.94	
0 A HALT	43 6.8884	6.9	28.1	5.88	
0 A HALT	43 4.9228	4.9	30.1	4.00	
0 A HALT	43 3.1294	3.1	32.1	2.29	
0 A HALT	43 1.4861	1.5	34.1	0.71	
0 A HALT	43 .00000	0.0	36.2	-0.80	

EXAMPLES OF CALCULATIONS

4. Repetitive Dive - Calculate the total time required for three dives to 140 fsw (on air), each dive with a bottom time of 15 min, separated by a surface interval of 15 min.

Keystrokes	Display at End of Operation	AD	TT	SD	Comments
46 TR 1 IN	00 00000	.00000	.0000	-19.07	Initialize
140 ED	41 140.00	140.0	2.4	-14.76	First dive
12.6 ET	42 15.000	140.0	15.0	17.68	
0 A	41 .00000	0.0	34.1	- 1.20	
15 ED	42 49.100	0.0	49.1	- 8.28	Surface interval
140 ED	41 140.00	140.0	51.5	- 4.69	Second dive
12.6 ET	42 64.100	140.0	64.1	24.36	
0 A	43 .00000	0.0	91.1	- 0.68	
15 ET	42 106.10	0.0	106.1	- 4.09	Surface interval
140 ED	41 140.00	140.0	108.5	- 2.93	
12.6 ET	42 121.10	140.0	121.1	26.18	
0 A	43 .00000	0.0	162.1	- 0.34	Total time 162 min

EXAMPLES OF CALCULATIONS

5. Random Dive - Calculate the total time required for the following dive on air.
Descend to 100 fsw at 60 fsw/min
Stop for 10 min
Descend to 150 fsw at 25 fsw/min
Stop for 20 min
Ascend to 60 fsw at 30 fsw/min
Stop for 15 min
Ascend to 30 fsw at 60 fsw/min, then follow safe depth to surface.

Keystrokes	Display at End of Operation	AD	TT	SD	Comments
46 TR 1 IN	00 00000	.00000	.00000	-19.07	Initialize
100 ED	41 100.00	100.0	1.7	-16.99	
10 ET	42 11.700	100.0	11.7	1.52	
16 TR 2.5 IN	16 2.5000				Set descent rate
150 ED	41 150.00	150.0	13.8	6.09	
20 ET	42 33.800	150.0	33.8	39.28	
15 TR 3 IN	15 3.0000				Set ascent rate
60 ED	41 60.000	60.0	36.8	37.57	
15 ET	42 51.800	60.0	51.8	23.22	
15 TR 6 IN	15 6.0000				Set ascent rate
30 ED	41 30.000	30.0	52.3	22.75	
0 A	43 .00000	0.0	91.5	- 0.35	

EXAMPLES OF CALCULATIONS

6. Stage Decompression - Calculate decompression stop times for a dive to 180 fsw for 15 min on air.

Keystrokes	Display at End of Operation	AD	TT	SD	Comments
46 TR 1 IN	00 00000	.00000	.0000	-19.07	Initialize
180 ED	41 180.00	180.0	3.1	-11.57	
11.9 ET	21 15.000	180.0	15.0	30.51	Estimate 1st stop at 30 fsw from SD
30 ED	41 30.000	30.0	17.5	29.83	1st top O.K.
ST	45 6.0000	30.0	17.5	29.83	6 min stop time
6 ET	42 23.500	30.0	23.5	19.56	
20 ED	41 20.000	20.0	23.7	19.27	Ascend to next stop
ST	45 8.0000	20.0	23.7	19.27	8 min stop time
8 ET	42 31.700	20.0	31.7	10.10	
10 ED	41 10.000	10.0	31.9	9.90	
ST	45 16.000	10.0	31.9	9.90	Stop time between 13 and 16 min
13 ET	42 44.900	10.0	44.9	0.58	
ST	45 2.0000	10.0	44.9	0.58	
2 ET	42 46.900	10.0	46.9	- 0.32	Stop time 13+2 min = 15 min at fsw
0 ED	41 .00000	0.0	47.1	- 0.44	

EXAMPLES OF CALCULATIONS

7. Stage Decompression - Calculate decompression stop times for a dive to 180 fsw for 15 min on air, using 100 percent oxygen for decompression from 30 fsw. Allow 20 percent leakage of ambient gas around face mask.

Keystrokes	Display at End of Operation	AD	TT	SD	Comments
46 TR 1 IN	00 00000	.00000	.0000	-19.07	Initialize
180 ED	41 180.00	180.0	3.1	-11.57	
11.9 ET	42 15.000	180.0	15.0	30.51	
30 ED	41 30.000	30.0	17.5	29.83	Value 63 in Reg. 8
52 TR 1 IN	52 00001				Set oxygen mode
8 TR 12.6 IN	08 12.600				0.2(30+33) = 12.6
ST	45 4.0000				4 min stop time
4 ET	42 21.500	30.0	21.5	18.93	
20 ED	41 20.000	20.0	21.7	18.46	Ascend to next stop
8 TR 10.6 IN	08 10.600				0.2(20+33) = 10.6
ST	45 5.0000				5 min stop time
5 ET	42 26.700	20.0	26.7	8.74	
10 ED	41 10.000	10.0	26.9	8.42	Ascend to next stop
8 TR 8.6 IN	08 8.6000				0.2(10+33) = 8.6
ST	45 7.0000				7 min stop time
7 ET	42 37.900	10.0	33.9	- 0.83	
0 ED	41 .00000	0.0	34.1	- 1.05	Ascend to surface
52 TR 2 IN					Delete oxygen mode

List of Figures

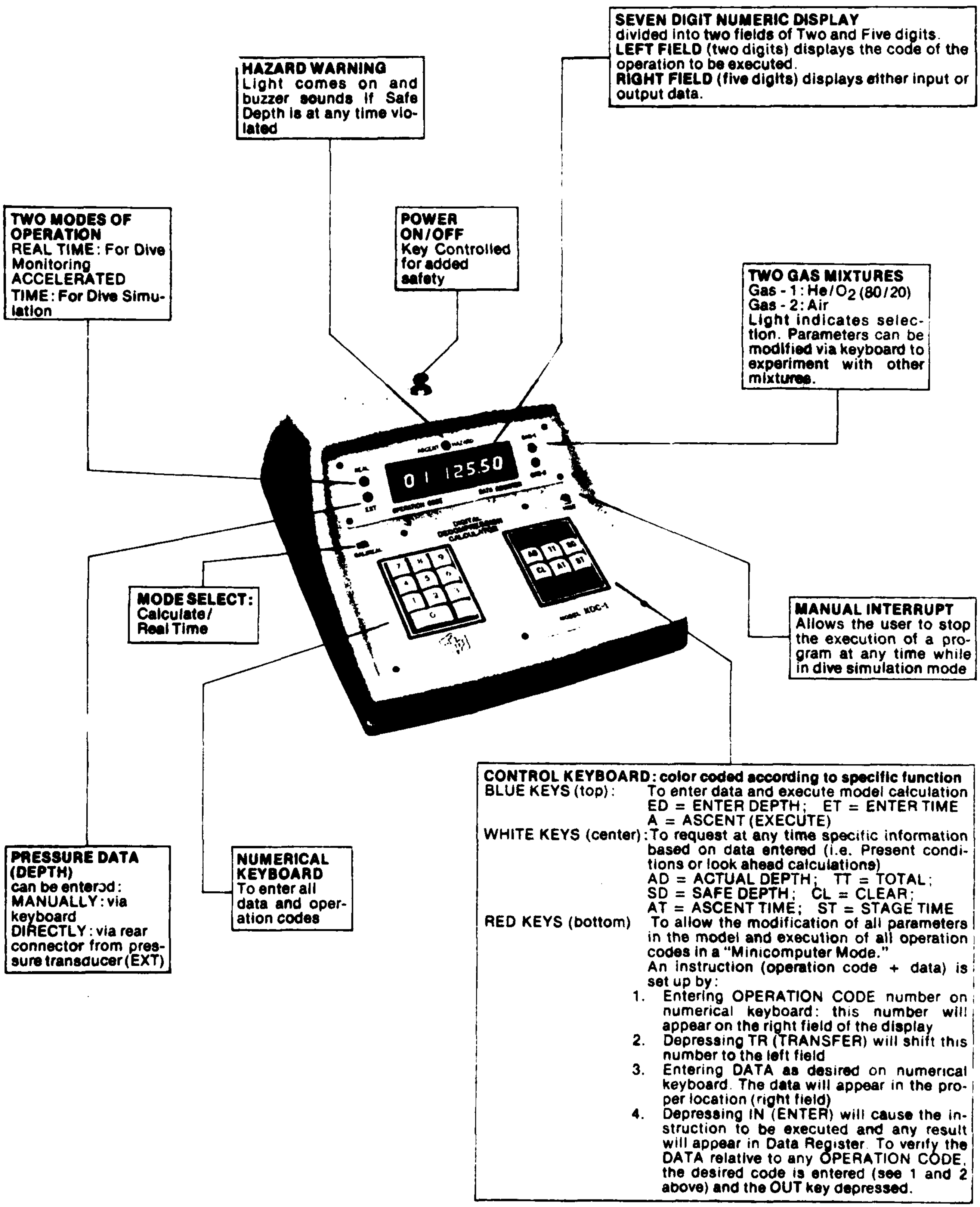

Figure 1. Features of the XDC-1 digital decompression calculator.

7	8	9
4	5	6
1	2	3
0		.

(a) NUMERIC INPUT KEYBOARD

FD	ET	A	BLUE KEYS
AD	TT	SD	WHITE KEYS
CL	AT	ST	WHITE KEYS
TR	OUT	IN	RED KEYS

(b) CONTROL KEYBOARD

Figure 2. Layout of numeric input and control keyboards.

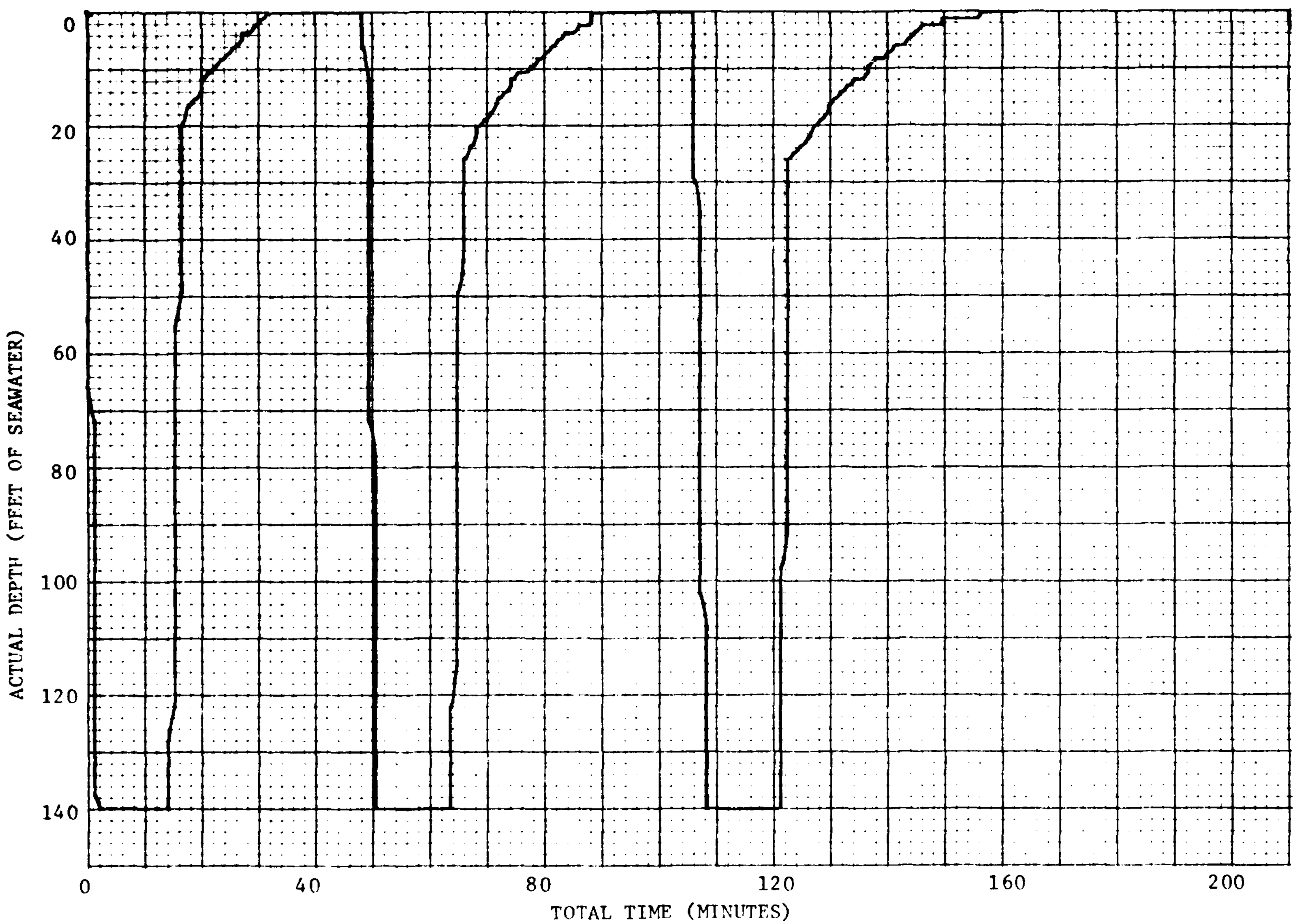

Figure 3. Example of a repetitive dive calculation (three dives to 140 fsw for 15 minutes separated by 15 minute surface intervals) plotted on a X-Y plotter through the analogue outputs. Actual depth is displayed on the Y-output and total time on the X-output. The output is not a smooth continuous curve since only an 8-bit digital-to-analogue converter is used.

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